http://doi.org/10.24867/JPE-2019-01-025

Journal of Production Engineering
Vol.22 No.1

JPE (2019) Vol.22 (1) Original Scientific Paper
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FIXTURES DESIGN FOR THIN-WALLED CYLINDRICAL WORKPIECES ON THE PRINCIPLES OF GROUP TECHNOLOGY

Received: 11 January 2019 / Accepted: 22 April 2019

Abstract: *This paper presents the methodology for fixture design based on the principles of group technology. The combination of the geometry-based and knowledge-based methods was used to develop a system for fixture design. The presented case study shows the implementation of the methodology for the inspection operations of the characteristic dimensions of the aluminium caps on a coordinate measuring machine.*
Key words: *fixtures, group technology, coordinate measuring machines*

Projektovanje pribora za tankozidne cilindrične delove na principima grupne tehnologije. *U radu je prikazana metodologija za projektovanje pribora zasnovana na principima grupne tehnologije. Kombinacija metode zasnovane na geometriji i metode zasnovane na znanju je upotrebljena za razvoj sistema za projektovanje pribora. U studiji slučaja je prikazana implementacija metodologije za operacije inspekcije karakterističnih dimenzija zatvarača na koordinatnoj mernoj mašini.*
Ključne reči: *pribori, grupna tehnologija, koordinatne merne mašine*

1. INTRODUCTION

A fixture is a device designed to repeatedly and accurately locate a workpiece in a position and orientation, relative to another workpiece or the reference frame of a machine tool or measurement machine [1]. Typically, fixtures are used during machining process, assembly or inspection operation. Badly embodied or poor quality fixturing solution can have a direct and detrimental effect on the output quality of a manufacturing system; with approximately 40% of rejected workpieces caused by dimensioning errors, being attributable to inadequate fixture design [2]. The costs associated with fixturing can account for 10–20% of the total cost of a manufacturing system [3]. These costs relate not only to fixture manufacture, assembly, and operation, but also to their design [4].

Fixture design is a complex task, which is a critical design–manufacturing link, especially in a modern computer integrated manufacturing environment [5]. Extensive investigations have been conducted in the area of fixtures design, which pertain to tolerance analysis, stability analysis, geometry analysis, accessibility analysis, swept volume analysis, stiffness-displacement analysis, kinetic analysis, locating analysis and clamping analysis. Lin and Huang [6] presented modular fixture planning system which combines the pattern recognition capability of the neural networks and the concept of group technology in order to group the workpieces with different patterns but identical fixture modes into the same group. The pattern classification capability of the back-propagation neural networks was used to develop the fixture planning. Lin and Huang [7] studied planning of modular fixtures for measurement using a coordinate measuring machine. Group technology was used to establish the coding database of the modular fixture element for use in the system. Several algorithms were developed to locate the appropriate fixture elements and their positions. Gologlu [8] presented a rule-based reasoning methodology for setup planning and datum selection incorporating machining and fixturing constraints. Liqing and Senthil Kumar [9] developed an internet-enabled case-based reasoning (CBR) system for modular fixture design. This CBR system was focused on representing XML-based fixture design cases using unified modelling language. Boyle et al. [10] developed a methodology to classify fixture design information into two libraries: conceptual design information and fixture unit information. Sun et al. [11] applied CBR algorithm for the modular fixture design. Memory organization packages technique was applied to organize locating data, knowledge and case base. Kang et al. [12] proposed a hybrid CBR/KBR (case-based reasoning/knowledge-based reasoning) fixture design method. KBR provided subset of possible fixture configuration. Then, CBR obtained a similar design of the fixture from the retrieving case database. Zheng and Qian [13] established a mathematical model of a prototype of modular fixture. They developed algorithms for automatic selection of the optimal fixel locations on the baseplates to precisely locate and firmly clamp the object. Ameri and Summers [14] introduced ontology for conceptualization and representation of domain knowledge in fixture design process. The proposed ontology was based on description logic, knowledge representation formalism and their interrelations. Vukelic et al. [15] used a combination of feature-based, knowledge-based and geometry-based methodology for developing an integral system for fixture selection, modification and design. Peng et al. [16] combined the rule-based reasoning (RBR) and CBR method for machining fixture design in a VR based integrated system. They proposed an effective fixture similarity measure method by hybrid using template retrieval and nearest neighbour algorithm. Zhang et al. [17] presented an ontology based method for fixture knowledge representation, retrieval and construction. Shape-based 3D model retrieval algorithm was employed to find similar fixture configuration from 3D model database. Based on retrieved models, an evolutionary method is presented to generate a new fixture. Hashemi et al. [18] proposed fixture design case indexing approach with a two-step case retrieval. The appropriate workpiece in the first level of database by using design requirement was found. Then, the proper conceptual fixture design can be achieved by retrieving related fixture case. Fu et al. [19] proposed a rule-based algorithm which defines fixture design for a set of operations. A rule-based algorithm was used to define all feasible manufacturing operations for the given computer-aided design (CAD) model. A hierarchical search technique is developed to discern which operations were best in terms of manufacturing time, cost, and fixture quality.

In contrast to previous investigations, the goal of this study is to develop a novel geometry-based and knowledge-based methodology for fixtures design based on the principles of group technology. The system allows fixture design for thin-walled cylindrical parts during their inspection on coordinate measuring machine (CMM).

2. METHODOLOGY

The basic requirement that is placed in front of group fixture is to provide the base and clamping of all workpieces of the group. Designing group fixture is much more complex than other types of fixtures because it is designed for a group of workpieces. Designing is based on an analysis of the structural and technological characteristics of workpieces belonging to the same group. When designing group fixture, it is necessary to pay special attention for the fixture to have:

- one body, with much universal application as possible,
- the smallest number of interchangeable and/or regulating elements.

The design of group fixtures for thin-walled cylindrical workpieces can be carried out in six steps, as follows:

1. defining a complex workpiece,
2. defining the locating and clamping scheme,
3. defining the shape of surfaces for locating and clamping,
4. defining characteristic dimensions,
5. selection of fixture elements,
6. fixture assembly.

At the beginning, as initial step, it is necessary to define the complex workpiece. It is a workpiece that contains all the elements of the workpieces in the group.

For the complex workpiece the locating and clamping scheme is defined. It is possible to define the following schemes:

- locating and clamping over the outer surface,
- locating and clamping over the inner surface,
- locating over the outer surface and clamping over the inner surface,
- locating over the inner surface and clamping over the outer surface.

Then, the shape of the surfaces for locating and clamping is defined. The characteristic surface shapes are:

- cylindrical outer / inner surface,
- straight outer / inner surface,
- conical outer / inner surface,
- torus outer / inner surface.

The next step defines the characteristic dimensions. The characteristic dimensions are the overall dimensions of workpieces through which the locating and clamping is carried out. Characteristic dimensions can be: length, height, width, diameter, etc. Then the fixture elements will be selected which will be used in the construction. The selection of individual elements is carried out according to predefined criteria, based on the declarative and procedural rules. Locating and clamping elements are selected based on geometrical and functional constraints. Therefore the selection is being made for: elements of the basic set of accessories, and interchangeable and/or adjustable fixtures. At the end, on the basis of the selected elements, the assembly of fixture is carried out.

3. CASE STUDY

Verification of the system is performed on the aluminium caps shown in Figure 1. These aluminum caps are usually used to seal glass bottles filled with mineral and natural waters, soft drinks and alcoholic beverages, pharmaceutical and technical content, juices, wines and other drinks.

Fig. 1. Aluminium caps

From the functioning point of view of the aluminium cap, the most important overall dimensions are the height (H), the outer diameter (d) and the inner diameter (D). The cap, together with its functional dimensions, is shown in Figure 2. In order to ensure measurement of the outer dimensions of the cap, it is necessary to locate it on the inner surface and to clamp over the outer surface. Locating of all caps is carried out through the opening, i.e. cylindrical inner surfaces.

The base element should be designed so that all the caps from the observed group can be reliably placed on it.

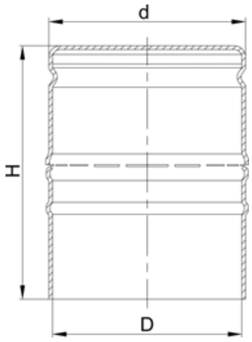


Fig. 2. Complex cap with functional dimensions

Clamping of the cap can be executed through a flat surface, i.e. the front surface of the cap which is shaped like a circle. The front surface of the clamping element must be of such dimensions as to enable the contact of the measuring styli with the cap during measurement on CMM. This means that the dimensions of the front surface of the clamping element should be selected in relation to the smallest diameter of cap seal. Other dimensions of cap do not affect the construction of the fixture. The functional dimensions of all caps are shown in Table 1. Figure 3 shows an example of a single cap with precise dimensions.

No.	d (mm)	D (mm)	H (mm)
1	$20.5^{\pm0.2}$	$20^{\pm0.4}$	$15^{\pm0.6}$
2	$28.5^{\pm0.2}$	$28^{\pm0.4}$	$15^{\pm0.6}$
3	$28.5^{\pm0.2}$	$28^{\pm0.4}$	$18^{\pm0.6}$
4	$32^{\pm0.2}$	$31.5^{\pm0.4}$	$18^{\pm0.6}$
5	$32^{\pm0.2}$	$31.5^{\pm0.4}$	$24^{\pm0.6}$
6	$28,5^{\pm0.2}$	$28^{\pm0.4}$	$38^{\pm0.6}$
7	$30,5^{\pm0.2}$	$30^{\pm0.4}$	$60^{\pm0.6}$
8	$31.5^{\pm0.2}$	$31^{\pm0.4}$	$40.5^{\pm0.6}$
9	$32^{\pm0.2}$	$31.5^{\pm0.4}$	$44^{\pm0.6}$
10	$32^{\pm0.2}$	$31.5^{\pm0.4}$	$57^{\pm0.6}$

Table 1. Characteristic dimensions of the cap

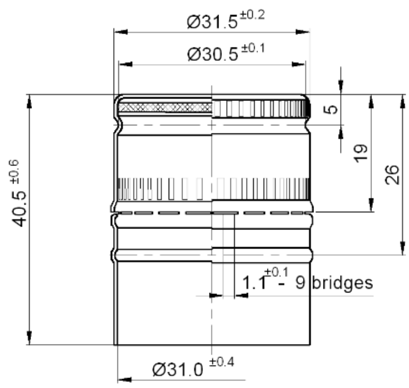
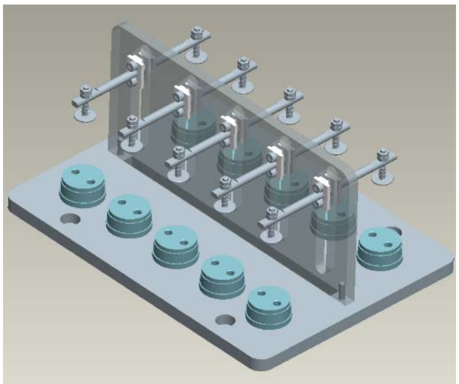


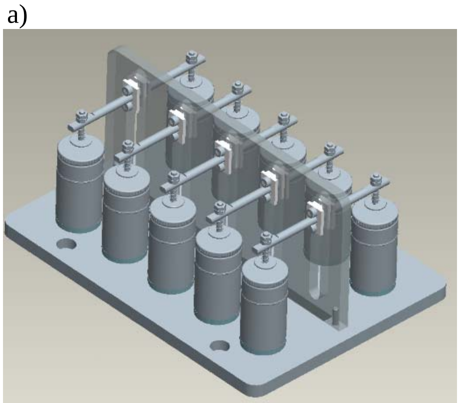
Fig. 3. Example of one aluminium cap

Using the procedural and declarative knowledge, along with respecting the geometry and dimensions of the characteristic areas of the cap, the selection of fixture elements was carried out. By assembling the elements, the group fixture is created and it is shown in Figures 4 and 5.

Group fixture is designed so that 10 caps are placed at the same time. Group fixture ensures the locating and clamping of all workpieces of the group without changing or regulating the fixture. Locating of workpieces is performed through a stepped plug. In this way, it is ensured that all workpieces are located on one base element. The clamping is performed mechanically through the threaded mechanism using the clamping elements so that the workpieces will not deform.



a)



b)

Fig. 4. CAD model of group fixture
a) without caps b) with caps

a)

b)

Fig. 5. Group fixture
a) without caps b) with caps

4. CONCLUSION

By analysing the problem of fixture design, it comes to the conclusion that it's irrational to use different fixtures for the same or similar operations. In order to reduce the number of fixtures, it is necessary to carry out their analysis and systematization. This can be done by grouping methods according to certain geometrical characteristics. Group fixtures ensure that a whole range of similar workpieces can be positioned and clamped in only one fixture. This results in a significant cost reduction.

The developed methodology provides fixture design for positioning and clamping of cylindrical workpieces on the principles of group technology. Designing process comes down to the design of the basic construction of fixtures and a certain number of interchangeable and adjustable elements. The selection of the elements is based on pre-defined production rules and on the geometrical characteristics of the workpieces.

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Acknowledgement

The results presented in paper have been obtained in the framework of the project "Advanced Technologies and Interdisciplinarity in Production Engineering" (Faculty of Technical Sciences in Novi Sad, Department of Production Engineering)

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